

Peculiar outburst of A 0535+26 observed with *INTEGRAL*, *RXTE* and *Suzaku*

I. Caballero^{* a}, K. Pottschmidt^b, L. Barragan^c, C. Ferrigno^d, P. Kretschmar^e,
S. Suchy^f, J. Wilms^c, A. Santangelo^g, I. Kreykenbohm^c, R. Rothschild^f,
D. Klochkov^g, R. Staubert^g, M. H. Finger^h, A. Camero-Arranz^{h,i,j}, K. Makishima^{k,l},
T. Mihara^l, M. Nakajima^m, T. Enoto^k, W. Iwakiriⁿ, Y. Teradaⁿ

^a CEA Saclay, DSM/IRFU/SAP – UMR AIM (7158) CNRS/CEA/Université P.Diderot – F-91191
Gif sur Yvette France

^b CRESST, UMBC, MD 21250 / NASA GSFC, Code 661, Greenbelt, MD 20771, USA

^c Dr. Karl Remeis-Sternwarte – FAU Erlangen-Nürnberg, 96049 Bamberg, Germany

^d ISDC Data Centre for Astrophysics, 1290 Versoix, Switzerland

^e ISOC, European Space Astronomy Centre, ESA, 28691 Villanueva de la Cañada, Madrid, Spain

^f Center for Astrophysics and Space Science, UCSD, La Jolla, CA, USA

^g Institut für Astronomie und Astrophysik, Sand 1, D-72076 Tübingen, Germany

^h NSSTC, 320 Sparkman Drive NW, Huntsville, AL 35805 USA

ⁱ Fundación Española de Ciencia y Tecnología / MICINN, Madrid, Spain

^j MICINN (Ministerio de Ciencia e Innovación), C/Albacete, 5, 28027, Madrid, España

^k University of Tokyo, Japan

^l RIKEN, Japan

^m Nihon University, Japan

ⁿ Saitama University, Japan

E-mail: isabel.caballero@cea.fr

A normal outburst of the Be/X-ray binary system A0535+26 has taken place in August 2009. It is the fourth in a series of normal outbursts that have occurred around the periastron passage of the source, but is unusual by starting at an earlier orbital phase and by presenting a peculiar double-peaked light curve. A first "flare" (lasting about 9 days from MJD 55043 on) reached a flux of 440 mCrab. The flux then decreased to less than 220 mCrab, and increased again reaching 440 mCrab around the periastron at MJD 55057. Target of Opportunity observations have been performed with *INTEGRAL*, *RXTE* and *Suzaku*. First results of these observations are presented, with special emphasis on the cyclotron lines present in the X-ray spectrum of the source, as well as in the pulse period and energy dependent pulse profiles of the source.

The Extreme sky: Sampling the Universe above 10 keV - extremesky2009,
October 13-17, 2009
Otranto (Lecce) Italy

*Speaker.

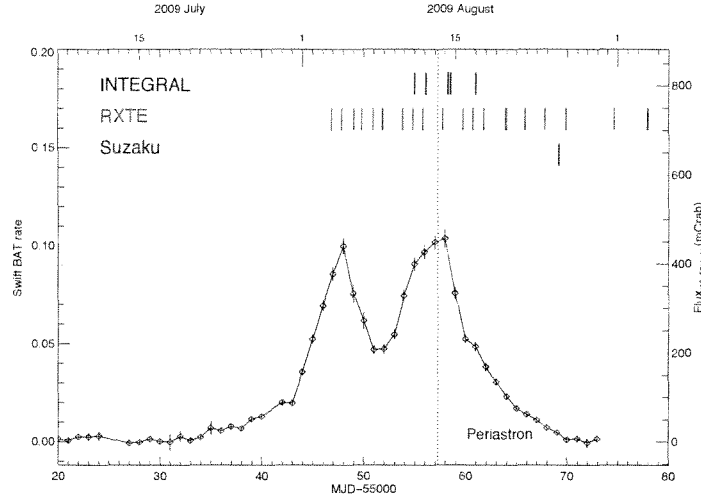


Figure 1: BAT 15-50 keV light curve of the peculiar August 2009 outburst of A 0535+26. The times of our *INTEGRAL*, *RXTE* and *Suzaku* TOO observations are indicated, as well as the periastron passage.

1. Introduction

A 0535+26 is a Be/X-ray binary system, discovered by Ariel V during a giant outburst in 1975 [1]. The binary system consists of the pulsating neutron star A 0535+26 and the optical companion HDE 245770. It lies in an eccentric orbit of $e = 0.47$ with an orbital period of $P_{\text{orb}} \sim 111$ days [2]. The estimated distance of the system is $d = 2$ kpc [3]. An extensive review is given in [4]. Since its discovery, five ¹ giant outbursts have been detected, in October 1980 [5], June 1983 [6], March/April 1989 [7], February 1994 [8] and May/June 2005 [9]. The source presents cyclotron lines in its X-ray spectrum. Cyclotron lines are very powerful tools, since they are the only direct way to determine the magnetic field of a neutron star. A 0535+26 shows two cyclotron lines at ~ 45 keV (fundamental) and ~ 100 keV (first harmonic). These lines were observed in 1994 with *HEXE* and *OSSE* ([11], [12]), and have later been confirmed with *INTEGRAL*, *RXTE* [13] and *Suzaku* [14]. From the cyclotron lines, the magnetic field is inferred to be $B \sim 4 \times 10^{12}$ G [15].

2. Renewed activity since 2005

As mentioned above, after more than 11 years of quiescence the source showed a giant outburst in 2005, which unfortunately could not be observed due to Sun constraints. Two subsequent normal outbursts took place in August/September and December 2005. Flaring activity was discovered during the August/September outburst, as well as associated changes in the cyclotron line energy and energy dependent pulse profiles. The cyclotron line was measured at ~ 52 keV during one of the flares, significantly higher than during the rest of the outburst [16]. These changes were

¹ At the moment of writing, December 2009, a new giant outburst of the source is taking place. [10]

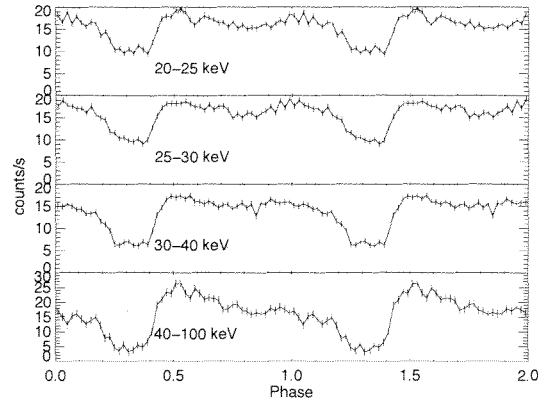


Figure 2: Energy dependent pulse profiles of A 0535+26 obtained with *INTEGRAL* *IBIS* (*ISGRI*).

interpreted in terms of magnetospheric instabilities developping at the onset of the accretion [17]. Since then, the source has shown several normal outbursts associated with the periastron.

The one from August 2009² is the fourth in a series of normal outbursts, but is peculiar, starting at an earlier orbital phase and showing an unusual double-peaked light curve. The *Swift*-*BAT* light curve (see Fig. 1) shows a first “flare” that lasted about 9 days from MJD 55043, about 14 days before the periastron, reaching a flux of 0.1 counts/s/cm² (440 mCrab) in the 15-50 keV *Swift*/*BAT* lightcurve before decreasing again to less than 0.05 counts/s/cm². The flux then rose again reaching 0.1 counts/s/cm² (440mCrab) in the *Swift*/*BAT* at MJD 55057 around the periastron ([19], [20]). This new outburst has led to our *INTEGRAL*, *RXTE* and *Suzaku* TOO observations being triggered. The times of the observations are shown in Fig. 1. A similar double-peaked normal outburst was already observed for A 0535+26 prior to the 1994 giant outburst [21].

3. First results

First results reveal pulsations of the neutron star with a spin frequency of $\nu = 9.6608[2]10^{-3}$ Hz and a derivative of $\dot{\nu} = 1.2[6] \times 10^{-12}$ Hz/s or a spin period of $P = 103.511[2]$ s and period derivative $\dot{P} = -1.2[6] \times 10^{-8}$ s/s, measured at MJD 55054.995 using *INTEGRAL* *IBIS* data. The orbital correction was performed using ephemeris from [2]. Energy dependent pulse profiles of one of our *INTEGRAL* observations are shown in Fig. 2. The pulse profiles show a double-peaked structure at lower energies, with one of the peaks being reduced above ~ 45 keV. These pulse profiles are very similar to pulse profiles of the source observed in the past (see e.g. [11], [21], [15]).

The X-ray continuum spectrum is modeled with an absorbed cutoff powerlaw. Absorption-like features are seen in both *RXTE* and *INTEGRAL* data, interpreted as cyclotron lines. We modeled the cyclotron lines using Gaussian lines in absorption [22]. As an example, an *IBIS* spectrum is shown in Fig. 3. From our first results, the best fit value for the fundamental cyclotron line

²The outburst subject of this work preceeds the December 2009 giant outburst, which is also taking place around periastron, about one orbital period after the August 2009 outburst [18].

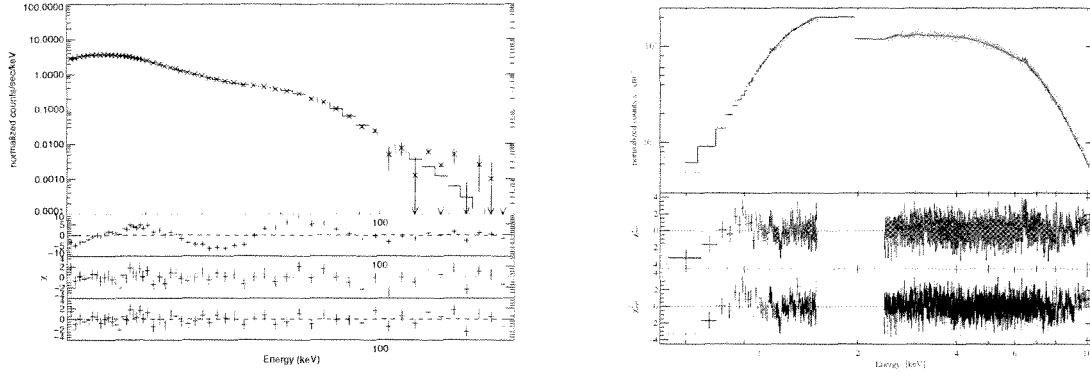


Figure 3: Left: *INTEGRAL* IBIS (ISGRI) spectrum of A0535+26. The upper panel shows the data and model, and the lower panels show the residuals of a fit including no absorption lines, one and two lines at ~ 45 and ~ 100 keV in the model. Right: *Suzaku* XIS spectrum of A0535+26. The upper panel shows the data and model, the middle and lower panel show the residuals of a fit without and with an Fe fluorescence line in the model.

is $E_{\text{cyc}} = 45.4^{+0.7}_{-0.6}$ keV for *IBIS* (ISGRI) and $E_{\text{cyc}} = 44.5^{+0.8}_{-1.1}$ keV for *HEXTE*. The *IBIS* data requires a second line fixed at 102 keV. These values are in agreement with the values obtained in past outbursts ([11], [14], [15]). First results from the *Suzaku* analysis are given in Fig. 3 (right), in which a XIS spectrum is shown. The 1.5-2.4 keV energy range is currently ignored due to calibration issues (ongoing work). We measure an Fe fluorescence line at $E = 6.42^{+0.03}_{-0.02}$ keV and an absorption column density of $N_{\text{H}} = 0.48 \pm 0.02 \times 10^{22} \text{ cm}^2$.

Making use of the *RXTE* observations (*PCA* and *HEXTE* data) we have studied the evolution of the cyclotron line energy during the outburst. Preliminary results are shown in Fig. 4. There seems to be no significant variation of the fundamental cyclotron line energy during the outburst. The analysis of the last observations at lower luminosity is still ongoing.

4. Conclusions and outlook

Work is ongoing to analyze the *INTEGRAL*, *RXTE* and *Suzaku* observations. One main goal is to study the dependence of the cyclotron line energy with the luminosity in order to probe changes of the accretion column height for different accretion rates of the source (see [23] and [24], [25], [26] and references therein). First results show no evidence for a change in the cyclotron line energy with the luminosity, suggesting that the line forming region is not changing with the luminosity of the system. This result is in agreement with what was found in the 2005 outburst [15]. We will also study the energy dependent pulse profiles during the outburst. Work is also ongoing to study the pulse period and spin-up of the source, evidence for an accretion disk. We will also search for possible QPOs, as already observed in the source in 1994 [21].

We are currently monitoring the current December 2009 giant outburst with *RXTE*. We plan to perform a detailed spectral and timing analysis of the new outburst, that will be related with the

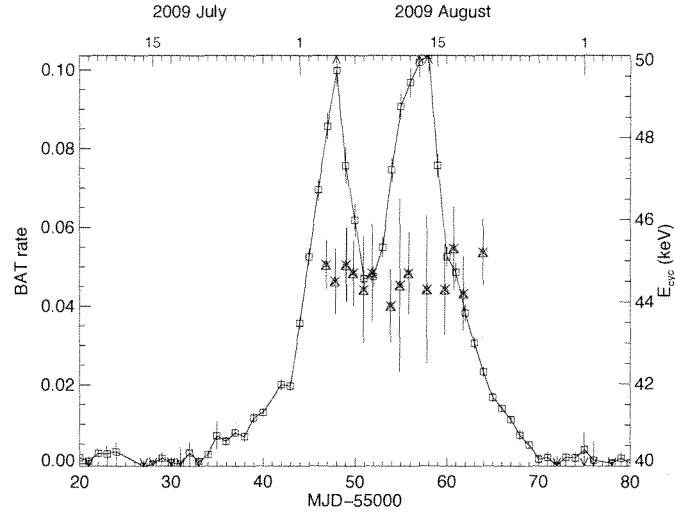


Figure 4: *Swift*-BAT light curve during the 2009 outburst (left axis, black squares) and cyclotron line energy as measured with *RXTE* (right axis, red triangles).

findings of the August 2009 outburst.

References

- [1] Rosenberg, F. D., Eyles, C. J., Skinner, G. K., & Willmore, A. P. 1975, *Nature*, 256, 628
- [2] Finger, M. H., Camero-Arranz, A., Kretschmar, P., Wilson, C., & Patel, S., 2006, *Bulletin of the American Astronomical Society*, Vol. 38, 359
- [3] Steele, I. A., Negueruela, I., Coe, M. J., & Roche, P., 1998, *Mon. Not. R. Astron. Soc.*, 297, L5
- [4] Giovannelli, F., & Graziati, L. S., 1992, *Space Science Reviews*, 59, 1
- [5] Nagase, F., Hayakawa, S., Kunieda, H., et al. 1982, *ApJ*, 263, 814
- [6] Sembay, S., Schwartz, R. A., Orwig, L. E., Dennis, B. R., & Davies, S. R. 1990, *ApJ*, 351, 675
- [7] Makino, F., Cook, W., Grunsfeld, J., et al. 1989, *IAU circ.*, 4769
- [8] Finger, M. H., Wilson, R. B., & Hagedorn, K. S., 1994, *IAU Circ.*, 5931
- [9] Tueller, J., Ajello, M., Barthelmy, S., et al. 2005, *ATel*, 504
- [10] Wilson-Hodge, C. A., Finger, M. H., Camero-Arranz, A., Connaughton, V., *ATel*, 2324
- [11] Kendziorra, E., Kretschmar, P., Pan, H. C., et al. 1994, *A&A*, 291, L31
- [12] Grove, J. E., et al., 1995, *Astrophys. J.*, 438, L25
- [13] Kretschmar, P., et al., 2005, *ATel*, 601
- [14] Terada, Y., et al., 2006, *Astrophys. J.*, 648, L139
- [15] Caballero, I., Kretschmar, P., Santangelo, A., et al. 2007, *A&A*, 465, L21

- [16] Caballero, I., Santangelo, A., Kretschmar, P., et al. 2008, A&A, 480, L17
- [17] Postnov, K., Staubert, R., Santangelo, A., et al. 2008, A&A, 480, L21
- [18] Caballero I., et al., 2009, ATel, 2337
- [19] Finger, M. H., Beklen, E., & Camero-Arranz, A., 2009, ATel, 2142
- [20] Caballero I., et al., 2009, ATel, 2161
- [21] Finger, M. H., Wilson, R. B., & Harmon, B. A. 1996, ApJ, 459, 288
- [22] Coburn, W., Heindl, W. A., Rothschild, R. E., Gruber, D. E., Kreykenbohm, I., Wilms, J., Kretschmar, P., & Staubert, R., 2002, Astrophys. J., 580, 394
- [23] Basko, M. M., & Sunyaev, R. A., 1976, Mon. Not. R. Astron. Soc., 175, 395
- [24] Mihara, T., 1995, Ph.D. thesis, Dept. of Physics, Univ. of Tokyo
- [25] Tsygankov, S. S., Lutovinov, A. A., Churazov, E. M., & Sunyaev, R. A. 2006, MN RAS, 371, 19
- [26] Staubert, R., Shakura, N. I., Postnov, K., et al. 2007, A&A, 465, L25